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ABSTRACT

This concept paper outlines the rationale for a project on the development of science curriculum for K-8 high ability learners. The rationale was developed through a synthesis of major recommendations from national science reform reports and from a review of the literature on effective science curriculum for high ability learners. The paper begins with a summary of the background research, with emphasis on six key curriculum components: (1) developing an understanding of scientific concepts; (2) developing scientific inquiry skills; (3) developing a knowledge base in science areas; (4) developing interdisciplinary connections; (5) developing problem-based learning approaches; and (6) developing scientific habits of mind. Then major project objectives are outlined. These include: review of promising science curriculum materials for high ability learners; development of papers on key science concepts; development of a curriculum scope and sequence model; conducting a summer institute on teaching science to gifted learners; development of a set of exemplary science curriculum units; field testing of newly developed curriculum; and generation of scholarly publications. A glossary defines key terms and an appendix provides a synthesis of science report recommendations. (Contains 59 references.) (DB)

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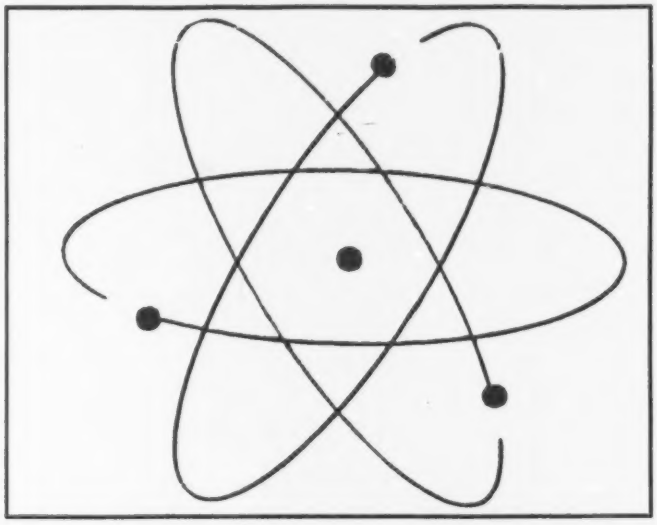
A CONCEPTUAL OVERVIEW OF SCIENCE EDUCATION FOR HIGH ABILITY LEARNERS



Developing Science Curriculum for High Ability Learners K-8

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The United States Department of Education

College of William and Mary
School of Education
Center for Gifted Education
Williamsburg, Virginia

1992

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A CONCEPTUAL OVERVIEW OF SCIENCE EDUCATION FOR HIGH ABILITY LEARNERS

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Overview

This concept paper outlines the rationale which will guide project work on the development of science curriculum for K-8 high ability learners. The rationale was developed through a synthesis of major recommendations from national science reform reports and from a review of the literature on effective science curriculum for high ability learners. Curriculum recommendations were made by linking the implications of reform recommendations and criteria for effective science curriculum with the specific learning needs of high ability learners. This synthesis was achieved through the collaborative efforts of project staff, consultants,scientists, science teachers, and gifted education specialists.

The concept paper begins with a summary of the background research and goes on to explain the rationale for the major elements of the project. The challenge section of the paper addresses each of the major project elements and provides direction for their accomplishment.

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Introduction

Science education in this country is experiencing several major and interrelated problems. Current national reports recommend a major shift in the organization of science curriculum from a content emphasis to a focus on key concepts and scientific principles taught through hands-on, real-world problem-solving approaches [American Association for the Achievement of Science (AAAS), 1989; 1990; Bennett, 1986; Hilton et al., 1989; National Science Board Commission, 1983; National Assessment of Educational Progress (NAEP), 1988]. Curriculum reform efforts which emanate from several disciplines highlight the need for curriculum that moves away from facts toward concepts, away from content coverage toward selective examples to support principles; and away from passive learning towards hands-on inquiry [Association for Supervision and Curriculum Development (ASCD), 1990).

Current curriculum and instructional problems, combined with the need to develop a literate scientific citizenry create a special kind of dilemma for science education. We have a school organizational structure at all grade levels that is too inflexible to accommodate serious science study: Laboratory time and hands-on classroom experiments require longer time periods than are typically allocated (NAEP, 1988), but science instructional time is significantly less than amounts allocated to other subject such as reading and math. Combined with the instructional time issue is the lack of training of teachers to do science with children in an appropriate way (AAAS, 1989; Bennett, 1986; National Science Board Commission, 1983). Most elementary and middle school teachers rely heavily on textbook worksheets and "canned" experiments for explaining science. Since science is poorly and infrequently taught at the elementary level, it has failed to sustain the involvement of all but the most interested students, those who have extra curricular resources to spark their continuing interest in science. The most tragic loss of continuing involvement in science is among special populations of high ability learners, most notably girls and minority children (Hilton et al., 1989).

Another part of the problem is education's failure to treat science as an active inquiry and to treat students as real investigators in the process of making meaning of their world. In order for science to be viewed as real inquiry, it must be taught in a way that strongly emphasizes science concepts, problem-based learning, and the cross-disciplinary nature of science. These needs of science education are complex, requiring solutions on several fronts simultaneously. Thus we need to address:

a) model curriculum that reflects the elements of the new science and standards appropriate for high ability learners.
b) profound changes in curriculum materials and how they are used;
c) instructional strategies that complement the new science and demonstrate effectiveness with a variety of learners;
d) enhanced teacher acceptance of the need for curriculum and instructional change and the provision of training towards this end; and
e) systemic change models that demonstrate how these dynamics interrelate.

Background Research

The National Science Teachers Association (NSTA) cites key areas for general science improvement (Harms and Yager, 1981):

Curriculum should:

- be problem-centered, flexible, culturally sensitive, and scientifically valid
- include people as the central ingredient
- use the natural environment, community resources, and current concerns
- be multifaceted with local and community relevance

- share a perspective that scientific information can be used for cultural/social purposes

Instruction should:

- be individualized and personalized
- constitute cooperative work on problems and issues
- be based on current research in developmental psychology

These NSTA recommendations provide a broad perspective of effective science curriculum and instruction. Additionally, the National Council of Project 2061 (AAAS, 1989) has also made general scientific literacy recommendations, including the importance of:

- being familiar with the natural world, and recognizing both its diversity and its unity
- understanding key concepts and principles of science
- having an awareness of the interdependence of science, mathematics, and technology
- having scientific ways of thinking
- using scientific knowledge for individual and social purposes

Moreover, a review of eleven recent science reports revealed common recommendations that make a strong case for emphasizing such process skills as problem-solving and critical thinking (see Appendix A for a chart of similarities and differences). The science community is also calling for students to be able to perform basic science skills such as observing and analyzing data. Emphasis is also based on content considerations: the strongest recommendation emanating from the national reports is that the science knowledge base ought to center around key concepts and principles rather than on discrete scientific facts. Content is not to be ignored, but depth should be more important than breadth. The reports also generally agree on the need for creative curricular strategies that promote scientific literacy. There is an overwhelming consensus that more instructional time is needed for hands-on science that is interdisciplinary in nature. Recent criticisms of science education by the scientific community include:

- a teaching force unable to provide appropriate level science content
- use of outdated textbooks
- little science education at the lower elementary levels

(A bibliography of these selected education reform reports may be found on pp. 20-21 of this paper.)

The most recent National Assessment of Educational Progress (NAEP) data are also worrying. Although 97% of 17-year-olds understand some basic scientific principles (e.g., simple knowledge about plants and animals), only 41% of these students have detailed scientific knowledge and can evaluate the appropriateness of scientific procedures. Even more alarming is the NAEP finding that only 7% of 17-year-olds can infer relationships and draw conclusions using detailed scientific knowledge.

In a recent test of science achievement involving students in 13 industrialized nations, the International Association for the Evaluation of Educational Achievement (1988) found that Americans rank ninth in physics, eleventh in chemistry, and last in biology. Stevenson et al. (1992) report that the top 10% of United States students in ability are only performing at the level of average ability students in Japan, Taiwan, and China by 5th grade in mathematics. Not only are Americans doing poorly in the sciences; but fewer and fewer of them are entering the science profession. By the year 2010, a shortage of at least 700,000 scientists and engineers is projected for the United States. Further, the National Academy of Sciences (1987) notes that while minority students constitute 20 percent of the college population, they account for only 1.6 percent of all math, science and engineering baccalaureate degrees, and women, who will constitute two-

thirds of the workforce by the year 2000, are also statistically under-represented, comprising only 15% of the 4.6 million engineers and scientists employed in the United States (National Science Foundation, 1988).

In order to maintain even the present number of scientists, the "attraction rate" of students to the sciences will have to increase significantly. The focus must not only be at the undergraduate level, but also at the elementary and secondary school levels if the United States is to achieve its goals for America 2000. Without an additional commitment in the public and private sectors to strengthen science education, we will continue to fail to meet the growing demand for highly trained scientists and science teachers.

These general concerns about the state of science curriculum in our schools are felt keenly by educators of high ability learners. The data clearly indicate that our top students are not ready to compete at world class levels (NAEP, 1990; Stevenson, et al., 1992). It is critical that high ability students have at least a functional knowledge of science, even if they do not enter careers in research or teaching. In our complex society, with the increasing involvement of science in matters of health, the economy, and national security, the general population needs to have a better understanding and appreciation of science, mathematics, and technology. Many high ability students do not experience an appropriately accelerated or enriched science curriculum during their elementary and middle school years: Often science is not even offered at the elementary level, although many high ability learners exhibit an unusual readiness to engage in inquiry and exhibit intense curiosity about the world around them, eager to participate in more concept-based work in science. It is also at elementary and middle grade levels that independent investigations involving science can be initiated and scientific processes can be explored in an interdisciplinary framework. However, in the majority of school districts in America, the textbook approach is the major delivery system for science curriculum, used primarily as a passive learning tool where children read and answer factual questions. Consequently, many gifted learners face boredom and remain unmotivated to learn this critical field of inquiry.

By overlaying the concerns of general science education with the special learning needs of gifted learners, we see common questions emerging. How do we infuse the curriculum with appropriate content and methodology? How do we improve science and technology literacy, especially among high ability students? How do we motivate students to see the joy of engaging in science inquiry? We must adapt existing materials and develop new materials which will assist us in addressing these questions.

Based on a review of three national studies about the needs of gifted learners (Weiss and Gallagher, 1982; Council for Exceptional Children, 1978; Richardson Report, 1984)), the College of William and Mary's Center for Gifted Education has identified four general needs in the area of gifted education:

- Curriculum reevaluation and development
- Development of new instructional materials
- Training programs demonstrating exemplary practices for teaching gifted learners
- More special programs in science and technology

Moreover, curriculum differentiation in various content areas has consistently been rated as a critical need by teachers of the gifted.

A review of the literature on effective science curriculum for high ability learners reveals the need for intensive work in science areas with many opportunities to master the inquiry process at a rigorous level (VanTassel-Baska, 1988, p. 222). This is directly related to the characteristics of gifted learners which enable them to handle a rigorous inquiry process:

- ability to handle abstractions
- power of concentration
- ability to make connections and establish relationships among disparate data
- ability to memorize well and learn rapidly
- possession of a wide information base with multiple areas of interest

VanTassel-Baska, et al (1988) further posit that appropriate curricula for gifted learners have three equally important dimensions:

1. *A content-based mastery dimension that allows gifted learners to move more rapidly through the curriculum.*

This dimension of the curriculum suggests that advanced science curriculum should be made available to the gifted when they demonstrate readiness to engage in it. Mastery of basic knowledge and skills in curriculum should allow students to move on to higher levels of science through the study of progressively more complex and sophisticated principles.

2 *A balanced process/product/research dimension that encourages in-depth small group and independent learning opportunities.*

This dimension of the curriculum calls for the engagement of gifted learners in the pursuit of real and meaningful scientific investigations, both collaboratively and independently. Problem-based learning and experimental design procedures provide a natural avenue for investigations that mirror real life science.

3. *An emphasis on the exploration of issues, themes, and ideas within and across curriculum areas.*

This curriculum dimension features scientific concepts and ideas as the organizers for educational experiences developed for gifted learners. These ideas, such as systems and change, allow students to see the integrated nature of the sciences and their relationship to other areas of study.

Gifted learners, therefore, need a science curriculum that is advanced and challenging. They also need a curriculum that provides opportunities for original investigations in science, using real world problems as a point of departure. Lastly, they need to study important scientific concepts that allow connections within science areas and across other areas of study to be made.

These dimensions of a gifted curriculum also provide a framework for addressing issues of differentiation among high ability learners. A systematic application of these dimensions of science curriculum yields a set of six key components to consider in curriculum development work.

1. <u>Developing an Understanding of Scientific Concepts.</u>

In a world of fragmented information and knowledge explosion, there is a need to organize areas of study more effectively. One of the most powerful ideas that emerged from a study of 120 scholars conducted by Shane (1981) was a recognition among leading scientists that students need to understand key concepts in science more than specific facts and that scientists could agree on what these concepts are. Particularly important was the need to communicate the role of humanity in science. Scientists in geology, physics, chemistry, and biology cited the following ideas as the most powerful organizers for a science curriculum for the year 2000:

Doctrine of limits	Evolution
Interdependence	Unity of nature
Entropy-conservation	People as agents of change
Population explosion	Human unpredictability
Nature of the scientific method	Plate tectonic theory

Firmly embedded in this list is a concern for the relationship between science and humanity. The teaching of ecology, for example, as a fundamentally interactive process is just one example of a natural inter-disciplinary connection that can be made and explored through teaching concepts rather than facts exclusively. Judson (1980) also used key science concepts to develop his powerful curriculum Search for Solutions, and concluded the text material with a set of unanswered scientific questions. Focus on scientific concepts is also a cornerstone of new work in science curriculum[e.g., Science for All Americans (Rutherford and Ahlgren, 1989)].

2 Developing Scientific Inquiry Skills

Just as one considers a shift in the organization of science curriculum toward key concepts, so too is there a need for a shift toward the student as investigator. Sternberg (1982) has outlined this major focus for gifted learners:

> . . . science education can and should be made more realistic, and should include training in problem finding, problem solving, problem reevaluation, and scientific reporting. Not only can such training be made realistic and representative of what scientists do, but it can serve as a motivator to those whose gifts may lie elsewhere. In this way, those who choose a career in science can make their choice on the basis of what doing science is like, rather than on the basis of a fiction that may resemble the style of academic coursework, but not the style of scientific research (p. 4).

An appropriate science curriculum should reflect an emphasis on more independent laboratory work, more extensive reading and emphasis on the skills of using the library, and more true experimental work (Brandwein, 1955; Brandwein and Passow, 1988). Scientific investigation does not necessarily have to be original research, but the curriculum should offer rich discovery opportunities.

Getzels and Csikszentmihalyi (1977) created an awareness of the critical role of problem-finding in making original contributions in the world of art. Problem-finding is also an important skill in the research paradigm of objective science. Selecting the right topic and asking the right questions are central to meaningful research. Helping learners form such questions is a critical part of their science education.

Cothron, Giese, and Rezba (1989) suggest the use of a four-question strategy to help students internalize experimental design procedures. These questions are:

1) What materials are readily available for conducting experiments on _____?
2) How does _____ act?
3) How can you change the set of _____ materials to affect the action?
4) How can you make sure of, or describe the response of _____ to the change?

Through following such techniques individually or in a small group, students learn to engage in scientific inquiry at a greater depth and internalize the basic procedures of experimental design.

In the world of science, discoveries are made slowly and painfully (Bruner, 1983). This principle must also be simulated in experiments in gifted science programs. Some of the best gifted programs in science, such as those at Bronx High School of Science and the North Carolina School of Math and Science, involve students

in such a way that they thoroughly understand that the nature of scientific endeavors is a part of an on-going and incremental process in a well-defined area of inquiry. One way to do this is to engage students in original research, an approach used in many laboratory-linked programs for the gifted (VanTassel-Baska and Kulieke, 1987). Preparation of research proposals as well as follow-up long-term projects enable students to internalize of the act of "doing" relevant science, rather than merely "simulate" science through "canned" experiments.

Another dimension of "real" science is making children aware of the unusual ways in which scientists often make discoveries accidentally. Young scientists need time to explore the nature of great experiments that influence our view of the world: what were the questions under investigation, and how did the scientists investigating those questions proceed with their inquiry?

The inclusion of a variety of science literature is also necessary to a quality science curriculum. Gifted learners can benefit from a close look at the history of scientific discoveries and the people who made the breakthroughs. In this way, eminent scientists and their science can become real. One excellent resource for this purpose is Great Scientific Experiments by Ron Harre. In this book, Harre treats twenty key experiments as case histories of scientists who used their creativity and ingenuity to understand nature. Other excellent books are: Watson's Double Helix and Konrad Lorenz's King Solomon's Ring. An excellent book on experimental design is Detheir's To Know A Fly.

Closely related to an understanding of doing real world science is the ability to work collaboratively in a research team. Given the nature of the knowledge explosion, no single person is capable of correlating all content knowledge for purposes of generating new knowledge. Consequently, an important model of science for the high ability learner to understand is that of collaboration (Goodfield, 1981). In the world of scientific research, many breakthroughs are made by scientific teams made up of individuals with specialized backgrounds, but with a scheme for working together on current scientific problems that requires combined knowledge from several areas. Work in biochemistry is a good example of this because biologists and chemists routinely address key research questions together. Even the trend in awarding the prestigious Nobel Prize in the sciences is toward a joint award to a team that has made a major contribution.

Student collaboration may be initiated through: 1) structuring small group investigations rather than individual ones, 2) using cooperative learning principles, 3) using creative problem-solving strategies in groups, and 4) working with real scientists in mentorships.

3. Developing a Knowledge Base in Science Areas

Another key component of an appropriate science curriculum for high ability learners is the opportunity to learn significant content in science areas. Fundamental to learning content is the use of inquiry which needs to be the focus within which a strong science content is introduced and developed. Emphasis on equal exposure of students to content in the biological, physical, and geological sciences is also necessary to ensure that intradisciplinary understandings are developed. With certain National Science Foundation curriculum materials, which are strongly content-oriented and include BSCS biology, Chemistry study, IPS Science, and PSSC Physics, students improved more in the areas of process skills, analytical skills and creativity than did students using other curricula (Welch, 1984). It appears that science curriculum which has a significant content base and is organized conceptually can enhance the development of skills critical for doing science. Where high ability students are exposed to a heavy content emphasis, as is still the case with some basal text materials, it is critical that opportunities for testing out of content already mastered is provided along with opportunities for advanced work in science topics. Rutherford and Ahlgren (1990) integrate scientific knowledge requirements into a set of scientific views of the world. These include:

1) The structure and evolution of the universe.
2) The general features of the planet earth.
3) The basic concepts related to matter, energy, force, and motion.
4) The human organism as a biological, social, and technological species.
5) The human life cycle through all stages of development and maturation.
6) The basic structure and functioning of the human body.

The emphasis on learning an appropriate knowledge base in the sciences is then shaped by these views that guide the teaching of more discrete content.

4. Developing Interdisciplinary Connections

Historically, scientific discovery and technological advancement have often been harnessed to potentially destructive ends, a terrible example of which was the development of the atom bomb. Consequently, to teach science as a totally objective set of processes is to misrepresent the role of science in today's world. High ability students need to be exposed to the social issues surrounding the scientific enterprise and to develop a philosophy of science and a code of ethics that includes concerns for the moral and ethical dimensions of "doing" science. Furthermore, recent statements from the National Science Teachers Association have reiterated the importance of integrating the study of science and the study of technology (NSTA, 1985) and many recently developed science materials make a major effort to infuse technology into required student texts (BSCS study, 1988).

One of the major recommendations emanating from several recent national reports stressed the need for updating the scientific information shared with students and for infusing the curriculum with new technological advances (National Science Board, 1983; AAAS, 1989). Specifically, science programs for high ability students should present technological issues as a part of each formal topic in the standard curriculum (VanTassel-Baska, Landau, and Olszewski, 1985). A key resource which addresses this purpose is the book and television series entitled Connections (Burke, 1988). These materials trace the common tools of today's technology back to their original scientific roots.

Infusion of technological advances into the curriculum should be a two-fold process: making use of technological tools that aid learning (e.g., computer simulations, video-discs, CD-ROMS); and the inclusion in the curriculum content of the technological advances that affect society (e.g., telephone, laser or medical technology). In each case, it is as important for students to see the application of these advances as it is to know of their existence.

Making the connection between science concepts and other areas of inquiry such as the social sciences, mathematics, and language is also crucial to meaningful science learning. As students study the concept of scientific systems, for example, it is helpful to link that study to systems of government, systems of economics, and various language systems. This forging of deliberate connections to other disciplines provides a richer and more complex curriculum for high ability learners.

5. Developing Problem-Based Learning Approaches

The goal of problem-based learning is to make learning in school more closely parallel the life-long learning which occurs beyond the school. An important consideration in developing science curriculum is, therefore to consider ways in which students may be helped to become vested, like "real-world" scientists, in the process of "doing" science.

Traditional curriculum structure has a well-established order of instruction: information comes first, followed by questioning to determine student understanding, and ending with some sort of problem-solving activity. While this approach is very systematic and easy for teachers to manage, it does not reflect the kind of learning which takes place in the "real world", especially in the science professions.

In problem-based learning, the ill-structured problem comes first, not last, in the learning sequence. On the first day of instruction, students are presented with an ill-structured dilemma. Questions which inevitably arise from the ambiguity in the situation lead to a reiterative process of speculation, problem definition, information, analysis, and problem redefinition. Eventually, students settle on a problem definition which they think is "core" to the situation and work towards its resolution. The instructor acts as a tutor/facilitator, analyzing the students' questioning process instead of directly providing information. As a metacognitive coach, the instructor not only facilitates group work, but also prompts students to become aware of the reasoning skills they are using. Basic assumptions of the problem-based methodology are:

1) The problem, "ill-structured" to resemble the nature of problems as they occur in the real world, comes before all else.
2) The teacher models, coaches, provides a scaffold for the students, and then fades into the background to become an observer and tutor of metacognition.
3) Transfer is enhanced through the use of multiple tasks and problem contexts to help form functional abstractions.
4) Active engagement with real problems and collaboration among learners are used for their motivational effects.

(adapted from Stepien, 1991)

When properly implemented, problem-based curriculum bears a remarkable resemblance to science as practiced by professionals. Notable scientists have observed that the public perception of science is limited to the practice of the experimental method, and although the experimental method is a part of science, it does not encompass the whole range of activity which is at the heart of being a scientist. Specifically, creating a fascination with the unknown, and the reiterative process of problem definition and questions are often left out (Judson, 1980; Medawar, 1979). A parallel between the real practice of science and problem-based learning has revealed the following similarities:

1) Ill-structured, unclear situations which stimulate questions.
2) Need for investigation stemming from the questions.
3) Research which stems from the question
4) Problem re-definition based on initial data.
5) Additional research
6) Resolutions/solutions which generate new questions

In addition, problem-based curriculum facilitates the study and discussion of the interrelationship between science and social structures such as government and economics. With laboratory experiences carefully structured within the investigation of the problem, problem-based curriculum becomes an encapsulation of the entire process of scientific thought, investigation and impact.

6. Developing Scientific Habits of Mind

Welch (1984) noted the importance of understanding the activities, beliefs, and personal traits of scientists in order to make appropriate inferences about an appropriate science curriculum. Most scientists share a

common set of fundamental beliefs about the natural world. These include such ideas as the existence of universal physical laws, the Copernican theory, and evolution. Such shared beliefs are subject to question and can radically change if experimentation or observation of the world indicates that they do not accurately reflect the true nature of things. Thus science, unlike some other domains of study, is more dependent on experiment and inquiry. It is therefore important to convey to students both the fundamental ideas of science and the methods by which these ideas are tested and refined.

Welch also notes that certain personality traits seem to characterize the more successful scientists and provides us with important guidance on the appropriate way to structure a science program for high ability learners. Curiosity, creativity, and commitment were found to be the characteristics which help to define the successful scientist (Brandwein, 1955; Klemm, 1977).

Teachers need to model the beliefs and traits of scientists as they instruct students in the activities of science in order to be effective role models in the process of scientific inquiry. Effective science programs are those that have inquisitive, creative, and committed teachers who prod students to exhibit these traits also. Thus the creation of scientific habits of mind requires that attention be paid to the development of cognitive and affective characteristics in the learner. Figure 1 reflects the salient features of scientific inquiry described by Welch.

Figure 1
Domains of Science Inquiry

Activities	Beliefs	Personal Traits
	About Nature	
Observation	Intelligible	Curiosity
Measurement	Causal	Creativity
Experimentation	Noncapricious	Commitment
Communication		
Mental Processes	About Method	
Induction	Objectivity	
Deduction	Skepticism	
Form hypotheses	Replication	
Create theories	Parsimony	
Analysis		
Synthesis	About Knowledge	
Extrapolation	Structure	
Evaluation	Explanation	
Estimation	Prediction	
Speculation	Tentative	

Source:Wayne W. Welch (1986). "A Science-Based Approach to Science Learning." In D. Holdzkom and P. Lutz (Ed.), Research Within Reach: Science Education. Washington,DC: National Science Teachers Association.

In summary, the literature is suggestive of science curriculum for high ability learners that incorporates the following goal structure:

- To study broad scientific concepts of merit that have meaning in all domains of science
- To engage in scientific investigation
- To provide indepth opportunities to learn special topics in science
- To understand the role of science in society, including the relationship of science to all other areas of human activity

- To foster curiosity about the world of science through the application of problem-based learning
- To master the tools of science by understanding the activities, beliefs, and characteristics of scientists

Women and Minorities in Science

While current theory and research provide a direction for establishing sound science programs for high ability students at a general level, we need to focus more sharply on the plight of women and minorities in science. Curriculum implications for encouraging girls and minorities to continue studying mathematics and science have emerged as a major issue over the last twenty years. Research on persistence in math, science, and engineering (MSE) students indicates a vast underrepresentation of minority students. The literature points to poor pre-college preparation as the major factor behind minority student attrition in MSE. The National Science Foundation noted in its 1986 biennial report, Women and Minorities in Science and Engineering that minority students' lower participation in advanced precollege math and science courses is the most crucial immediate concern of minorities in MSE. The most common precursor to poor science performance in college was found to be elementary and secondary school preparation in math and science (Chipman and Thomas, 1984).

Several studies have cited the lower enrollment of women compared to men in advanced coursework in these areas and fewer women in careers related to science. Whereas studies have cited several possible reasons for this discrepancy that may be found in the social (Eccles, 1984), psychological (Astin, 1969), and biological (Benbow and Stanley, 1980) milieus, it is a discrepancy that cannot be ignored when addressing the needs of gifted females and minorities. Consequently, it is important for curriculum planners to be conscious of the need for emphasizing appropriate approaches in nurturing the interest of gifted girls and minority students in science programs.

An example of such an emphasis is Project Link in Minnesota, a prototype program for high ability girls in grades 4-6 who are potentially interested in science and math careers. The program seeks to provice career role models for girls from the local community. Adult females come into the classroom to address various career-related issues and opportunities to visit professional women at work are also arranged. Such a program emphasizes careers in mathematics and science for girls, and at the same time provides real-life role models in science and science-related professions.

Helping high ability girls to understand the importance of taking four years of high school math and science should be another important thrust of a program. Since only 1 out of every 300 gifted girls pursues a doctorate, it is important to demonstrate the relationship of early educational attainment in the areas of math and science as a way to broaden the choice of future educational and career paths. Small group discussions and films like Count Me In: Educating Women for Math and Science are excellent ways to foster these ideas. Bibliotherapy techniques that focus on reading biographies of women and minority scientists and works written by them may also be useful in enhancing involvement in the sciences.

The literature suggests several strategies for maintaining female and minority interest in the sciences (VanTassel-Baska, 1988, p. 238):

- Present information about women and minorities who have careers in science and technology.
- Help girls and minorities to understand the effects of sex-stereotyping and bias in science and career materials on their self-perceptions.

- Provide information about contributions of women and minorities in science.
- Explain the projections for science and engineering careers over the next decade.
- Relate the changing roles of men and women to the career potential for women in science.
- Select materials that avoid sex and minority stereotypes in their illustrations (e.g., pictures in which women are actively engaged in science, outdoors as well as indoors, and in which as many men are looking over women's shoulders and vice versa).
- Invite women and minority scientists into the classroom to talk about relevant topics.
- Encourage all students to develop manipulative hobbies, such as butterfly collecting, photography, computers, or constructing models and radios.

Science is a human endeavor. If we are to do anything to effect change in the quantity and quality of women and minority scientists, it is important to provide positive early science experiences, which are generated from a solidly defined elementary and middle school science curriculum.

The Challenge

Coherent curriculum evolves from a strong rationale and goal structure. The conceptual framework for developing science curriculum for high ability learners described in this paper provides a basis for the development of specific recommendations on science curriculum for such learners. Given the dynamic nature of science and the concurrent information explosion, any curricular proposals will need to be flexible and responsive to change Moreover, it will need to demonstrate exportability, the capacity for generalizability to different learning contexts and school settings. The major challenge of the project is to find consistent ways to translate all of the desirable components described in this paper into usable products in our nation's classrooms.

Project Objectives: A Plan for Action

The purpose of this project is to develop science recommendations for high ability learners K-8 that respond to both the needs of such learners and the reconfiguration of science education. The project will meet the following objectives:

1) Promising science curriculum materials for high ability learners will be reviewed according to a curriculum evaluation system that develops criteria for judging exemplary science curriculum. By delineating a set of curriculum standards, this evaluation system will provide schools with a template for reviewing any new science curriculum materials that are teacher-made or commercially developed according to general curriculum design features, exemplary science features, and tailored for high ability learners. Specifically, evaluation criteria for the review of curriculum materials will include an assessment of the curriculum's general curriculum design features (rationale and purpose, content, and responsiveness to developmental needs); classroom design features (instructional objectives, activities, instructional strategies, assessment procedures, materials resources, and extension ideas); and technology features. A separate review will address issues of exemplary science inquiry, including both science content and science process features. The last phase of the review process will focus on differentiation for high ability learners. This segment of the review process will also look more specifically at issues of curriculum responsiveness to intellectually gifted learners, science-prone students, girls, minorities, and disabled students.

2) A set of concepts will be recommended as organizers for new science curricula for high ability learners. These concepts will be developed into concept papers that delineate the significance of the concept to science inquiry, the relationship of the concept to other fields of study, and the application of the concept to teaching and learning at K-8 levels.

3) A scope and sequence model for K-8 science curriculum will be developed that selects one concept and develops it systematically from generalizations to learner outcomes to content applications at the grade levels of K-2, 3-5, and 6-8. The scope and sequence model will provide an organizing structure for the development of instructional units.

4) A Summer Institute in Teaching Science to Gifted Learners will be held during the summer of the grant period. The purpose of the Institute is to prepare teachers to develop exemplary science curriculum units for high ability learners at K-8 levels. Participants will be selected according to the following criteria: a) accessibility of the school site to project staff for follow-up pilot testing, b) background experience in working with gifted learners, preferably in science, and c) at least one course in curriculum development for high ability learners. The participants will examine the issues and criteria relevant to developing quality science curriculum for advanced elementary and middle school learners.

5) A set of exemplary science curriculum units will be developed for primary, intermediate, and middle school levels. These units will be generated from the project's selected concept, will follow the scope and sequence guidelines, and be evaluated according to the project criteria for exemplary science curriculum materials. It is expected that the newly developed curriculum units will meet the criteria for exemplary science inquiry for gifted learners and will be so evaluated.

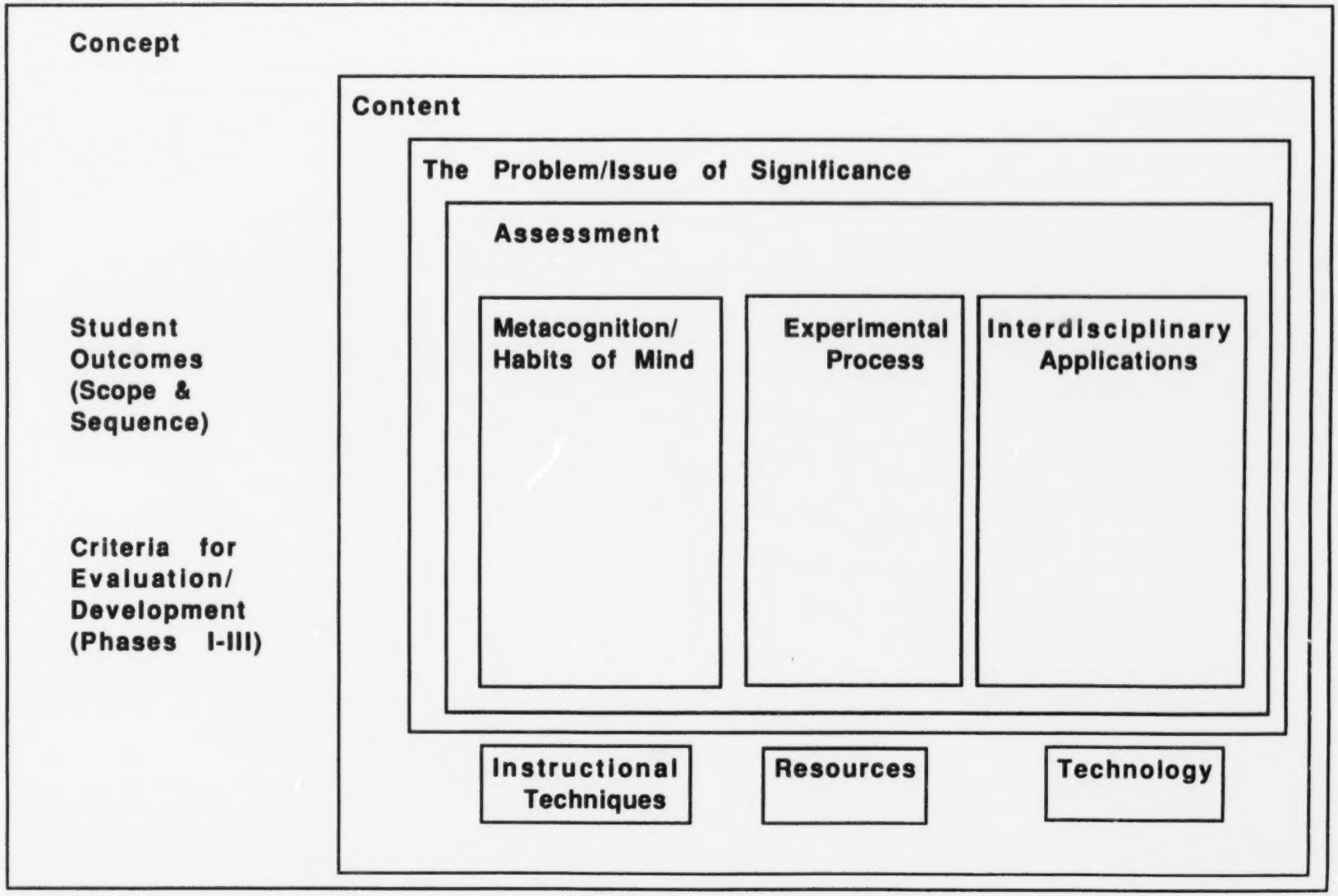
6) Field testing of newly developed curriculum units will be done in the classrooms of teachers selected for the Institute. The field testing will provide an operational evaluation mechanism for determining the applicability of the written curriculum to classroom practice. Following the field testing, project staff will revise the unit products, based on teacher log data and observational data collected during the field testing.

7) Scholarly publications will be generated from this project that describe and document the criteria for high quality science curriculum for high ability learners and describe the relevant issues of constructing a coherent science curriculum for such learners.

All phases of this curriculum project will be based on the ideas detailed in this concept paper. The curriculum evolves from an understanding of the critical science concepts that shape our objective world and the organization of those concepts into a set of student outcomes from kindergarten through eighth grade. The criteria for evaluating exemplary curricula also shape the broadest levels of curriculum work. At the second level of the curriculum organizer is content, the translation of a science concept into various science domains, and into other interdisciplinary areas of study. At the third level of the organizer there lies a problem of significance approached through problem-based learning and assessments of learner outcomes. Problem -based learning requires students to grapple with an ill-structured problem in ways that enhance their curiosity to explore ideas, carry out research, and develop policy papers on the chosen problem. At the fourth level of the organizer are key components of science curriculum that address the instructional process. There is an emphasis on the scientific habits of mind that real scientists bring to the study of problems and on the experimental process, the procedures by which scientists do their work. There is an instructional emphasis on critical thinking and on metacognition, which involves helping students develop skills in planning, monitoring, and assessing what they are learning. At the fifth level of the organizer rests specific instructional considerations including strategies, resources, and technology. In sum, the curriculum organizer addresses all salient components of the project. Figure II delineates the evolving curriculum organizer used to integrate the various aspects of developing science curriculum for high ability learners.

Figure II

CURRICULUM ORGANIZER



A glossary of key terms used to define the curriculum organizing structure are found below.

Definition of Terms

Concept

A concept is generically defined as "an abstract idea or a generalized idea of a class of objects based on knowledge of individual members of that class." For purposes of this project, a concept is an overarching, scientifically grounded idea with underlying generalizations. A science concept can be translated into various science disciplines and also translated to disciplines beyond science. A concept can be progressively developed at more sophisticated levels and can be applied across grade levels. In this project, the concepts we have chosen for explication are: models, change, evolution, reductionism, scale, and systems.

Concept Outcomes

Concept outcomes are statements of learning expectations for students at K-2, 3-5, and 6-8 levels of the curriculum. For purposes of the project, the concept outcomes include both lower order and higher order expectations appropriate for high ability learners.

High Ability Learners

For purposes of this project, high ability learners refers to the approximately uppermost 20% of the school age population at all grade levels who evince a special aptitude for, or interest in, science.

Intellectually Gifted

This term refers to high ability students who are in the top 5% of general intellectual ability at their respective age levels as measured by valid and reliable psychometric instruments.

Interdisciplinary Applications

Interdisciplinary applications are conceptual connections made to two or more disciplines. In this project, the term may be used to describe the application of a key science concept and its generalizable components to areas of study outside of the domain of science, such as art, music, literature, and mathematics. For example, the concept of systems and its underlying generalizations can be applied to language and economics. Interdisciplinary applications may also refer to the linkage of any specific content topic to various disciplines of study. For example, the study of beetles might engage students in artistic representations of beetles, writing descriptions of beetles, and measuring and predicting the size of beetles, all of which are scientifically meaningful activities. Appropriate interdisciplinary applications thus may both honor a concept structure, and honor any activity using the tools of another discipline that aids in the meaningful understanding of a science topic.

Knowledge Footprint

A knowledge footprint is the specific treatment of a science topic within a unit of study. For example, the study of pH and the chemical reaction system would be a "knowledge footprint" within the topic of "kitchen chemistry."

Metacognition

Metacognition is thinking about thinking: It entails pondering, deliberating, or reflecting on a problem or situation; reviewing what is known and remembered about the kind of problem confronted; making decisions about what observations, or questions need to be made; questioning the meaning of new information, and reflecting on and reviewing what has been learned.

Problem-Based Learning

A sequence of instruction which is 1) initiated by the presentation of an ill-structured problem, 2) guided by learning issues associated with the problem and identified by the students and 3) geared toward successful resolution of the problem. Students take the role of problem solver; teachers act as metacognitive coaches, commenting only on the students' reasoning instead of "guiding" the discussion or providing information. Specific goals of the problem-based approach to instruction are to teach students "effective reasoning, the ability to self-evaluate and self-educate, to keep contemporary and safe, and to be critical and independent thinkers" (Barrows, 1985).

Science Process Skills

Science process skills are those skills that scientists use. For purposes of this project, science process skills are defined as the abilities to: explore a new scientific area; identify meaningful questions within that area; address meaningful questions through active experimentation of demonstrations; demonstrate good data-handling skills; analyze experimental data; evaluate results; make predictions about similar problems; and communicate findings to others through appropriate modes. These skills constitute the structure of inquiry which the project curriculum developers will use in developing curriculum products at all levels.

Science Prone

This term refers to high ability students who have a particular interest in and aptitude for doing science based on evidence of their prior and current work and involvement in science, and to other students particularly motivated to learn science.

Scientific Habits of Mind

Scientific habits of mind are defined as "the values, attitudes and skills which relate directly to a person's outlook on knowledge and learning and ways of thinking and acting" (Rutherford,1989). For science, the list includes reasoned skepticism, tolerance of ambiguity, curiosity, openness, the ability to perform scientific operations associated with numeracy, scientific experimentation and communication. When combined with metacognition, this means that students can responsibly identify the skills needed to complete a task and apply them purposefully.

Topic

A topic is generically defined as "the subject of a writing, speech, or discussion." In this project, a topic is a specific subject matter manifestation of a scientific concept used at a particular stage of development. The focus of teaching units is on individual "topics", specifically connected to the concept of systems but loosely connected to each other. Sample topics appear in the scope and sequence model for each concept and provide specific examples in biology, geology, or physical science areas. For example, kitchen chemistry would be the topic of study within the science discipline of chemistry for grades 3-5.

Summary

A conceptual re-thinking of what science is and how it should be taught is the task facing today's educators in creating scientists of the future. Shaping a new conception of curriculum, particularly for the high ability learners who will become tomorrow's scientists, requires a careful consideration of many variables. Quality curriculum design needs to be supported by excellent materials and resources that respond to characteristics of high ability learners and typify the "new science." and teachers must be trained in developing and implementing exemplary curriculum. Integrating these variables into an effective whole remains the ultimate challenge for educators of high ability learners.

Bibliography

Astin, H. (1969). The Woman Doctorate in America. NY: Russell Sage.

Barrows, H.S. (1985). The Tutorial Process. Springfield, IL: Southern Illinois University of Medicine.

Benbow, C., & Stanley, J. (1980). Sex differences in mathematical ability: Fact or artifacts? Science, 210, 1262-1264.

Biological Sciences Curriculum Study Group (1988). Science for Life and Living: Integrating Science, Technology, and Health. Washington, DC: National Science Foundation.

Brandwein, P.F., & Passow, A.H. (Eds.) (1988). Gifted Young in Science: Potential Through Performance. Washington, DC: National Science Teachers Association.

Brandwein, P.F. (1955). The Gifted Student as Future Scientist. NY: Harcourt, Brace, Jovanovich.

Bruner, J. (1983). In Search of Mind. NY: Harper and Row.

Burke, J. (1978). Connections. Boston: Little, Brown and Company.

Chipman, S., & Thomas, V. (1984). The Participation of Women and Minorities in Math, Science, and Technical Fields. Office of Naval Research.

Cothron, J., Giese, R., & Rezba, R. (1989). Students and Research. Dubuque, IA: Kendall-Hunt.

Council for Exceptional Children (1978). The Nation's Commitment to the Education of Gifted and Talented Children and Youth. Reston, VA.

Dethier, V.G. (Vincent Gaston) (1962). To Know A Fly. Illustrated by Bill Clark & Vincent Dethier. San Francisco: Holden-Day.

DeVito, A., & Krockover, G. (1979). Creative Sciencing. Boston: Little, Brown and Company.

Eccles, J. (1984). Sex differences in mathematics participation. In M. Steinkamp and M. Maehr (eds.), Women in Science. Greenwich, CT: J.A.I. Press.

Feldhusen, J. F., VanTassel-Baska, & Seeley, K. (1989). Excellence in Educating the Gifted. Denver, CO: Love Publishing Company.

Gallagher, J. (1985). Teaching the Gifted Child. Boston: Allyn & Bacon.

Gallagher, J.J., Weiss, P., Oglesby, K., & Thomas, T. (1982). Report on Education of Gifted, Volume I, Surveys of Education of Gifted Students. Chapel Hill, NC: University of North Carolina.

Getzel and Csikszenmihalyi (1977). The Creative Vision. Chicago: University of Chicago Press.

Goodfield, J. (1981). An Imagined World: A Story of Scientific Discovery. NY: Harper and Row.

Harms, N., & Yager, R. (1981). What Research Says to the Science Teacher, Volume 3. Washington, DC: NSTA Monograph

Harre, R. (1981). Great Scientific Experiments. Oxford: Oxford University Press.

Haugen, D. (1984). Presentation to Summer Institute on Curriculum Development for Teachers. Northwestern University.

Hilton, T.L., Hsia, J., Solorzano, D.G., & Benton, N.L. (1989). Persistence in Science of High-Ability Minority Students. Princeton, NJ: Educational Testing Service.

Illinois Office of Education (1978). Survey of Provisions for Gifted Children in Illinois. Springfield, IL.

Judson, J. (1980). Search for Solutions. Bartlesville, OK: Phillips Petroleum Company.

Klemm, W.R. (Ed.) (1977). Discovery Processes in Modern Biology. Huntington, NY: Robert E. Krieger Publishing.

Lorenz, K. (1952). King Solomon's Ring: New Light on Animal Ways. NY: Crowell.

Medawar, P.B. (1979). Advice to a Young Scientist. NY: Basic Books.

Richardson Study of Gifted and Talented Education (1984). Fort Worth, TX: Richardson Foundation.

Rutherford, F., & Ahlgren, A. (1989). Science for All Americans. NY: Oxford University Press.

Schumacher, G.M. (1987). Executive control in studying. In B. Britton, & S. Glynn (Ed.), Executive Control Processes in Reading. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Shane, H. (1981). Content Curriculum for the Future. NY: College Board, paper prepared for College Board.

Sternberg, R.J. (1982). Teaching scientific thinking to gifted children. Roeper Review, 4 (4), 4-6.

Stevenson, H. (1992). "Education of Gifted and Talented Students in China, Taiwan, and Japan". Paper presented at National Project Directors' Meeting, Washington, DC.

VanTassel-Baska, J., Feldhusem J.F., Seeley, K., Wheatley, G., Silverman, L., & Foster, W. (1988). Comprehensive Curriculum for Gifted Learners. Boston, MA: Allyn and Bacon.

VanTassel-Baska, J. (ed.) (1987). A Curriculum Guide to Applications of Science and Technology for Able Learners. Evanston, IL: Northwestern University, Center for Talent Development.

VanTassel-Baska, J., & Kulieke, M. (1987). The Role of the Community in Developing Scientific Talent. Gifted Child Quarterly, 31 (3), 115-119.

VanTassel-Baska, J., Landau, M., & Olszewski, P. (1985). Toward developing an appropriate math/science curriculum for gifted learners. Journal for the Education of the Gifted, 8 (4), 257-272.

Waller, R. (1987). Typography and reading strategy. In B. Britton, & S. Glynn (Ed.), Executive Control Processes in Reading. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Watson, J.D. (1968). The Double Helix: A Personal Account of the Discovery of the Structure of DNA. NY: Atheneum.

Welch, W.W., Klopfer, L.E., Aikenhead, G.S., & Robinson, J.T. (1981). The role of inquiry in science education: Analysis and recommendation. Science Education, 65 (1).

Welch, W. (1986). "A Science-Based Approach to Science Learning." In D. Holdzkom and P. Lutz (Ed.), Research Within Reach: Science Education. Washington, DC: National Science Teachers Association.

Selected List of Education Reform Reports

Association for Supervision and Curriculum Development (1990). Update. Alexandria, VA: ASCD.

American Association for the Advancement of Science (1989). Science for All Americans. (AAAS Publication 89-01S). Washington, DC: Author.

American Association for the Advancement of Science (1990). The Liberal Art of Science. (AAAS Publication 90-13S). Washington, DC: Author.

Bennett, W.J. (1986). First Lessons: A Report on Elementary Education in America. Washington, DC: U.S. Government Printing Office.

Carnegie Council on Adolescent Development (1989). Turning Points: Preparing American Youth for the 21st Century. Washington, DC: Author.

Carnegie Forum on Education and The Economy, Task Force on Teaching as a Profession (1986). A Nation Prepared: Teachers for the 21st Century. NY: Author.

Champagne, A.B. (Ed.) (1988). Science Teaching: Making the System Work. Washington, DC: American Association for the Advancement of Science.

Exxon Education Foundation (1984). Science Education in the United States: Essential Steps for Achieving Fundamental Improvement. NY: Author.

Hilton, T.L., Hsia, J., Solorzano, D.G., & Benton, N.L. (1989). Persistence in Science of High-Ability Minority Students. Princeton, NJ: Educational Testing Service.

International Association for the Evaluation of Educational Achievement (1988). Science Achievement in Seventeen Countries: A Preliminary Report. Oxford: Pergamon Press.

Klein, M.S., & Rutherford, F.J. (Eds.) (1985). Science Education in Global Perspective: Lessons From Five Countries. Boulder, CO: Westview Press.

Mullis, I.V.S., & Jenkins, L.B. (1988). The Science Report Card. Elements of Risk and Discovery: Trends and Achievement Based on the 1986 National Assessment. Princeton, NJ: Educational Testing Service.

National Assessment of Educational Progress (1988). Science Learning Matters. Princeton, NJ: Educational Testing Service.

National Governors' Association Center for Policy Research and Analysis (1986). Time for Results: The Governors' 1991 Report on Education. Washington, DC: Author.

National Research Council (1990). Biology Education in the Nation's Schools. Washington, DC: National Academy Press.

The National Science Board Commission on Precollege Education in Mathematics, Science, and Technology (1983). Educating Americans for the 21st Century. Washington, DC: National Science Foundation.

National Science Teachers Association (1985). Science-Technology-Society: Science Education for the 1980's, a position statement. Washington, DC: NSTA.

Appendix A

SYNTHESIS OF SCIENCE REPORT RECOMMENDATIONS

The chart below tabulates a synthesis of similarities and differences in the recommendations of eleven national reports which address the need for a heightened emphasis on such process skills as problem-solving and critical thinking in science curriculum. The numbers in parentheses refer to the reports listed numerically on the next page.

SIMILARITIES

CONTENT CONSIDERATIONS

*Need creative curricular strategies.(3,5,8)
*Restore notion of scientific method.(1,2,3,8)
*Teach basic skills (observing, analyzing data, etc).(2,7,8,9)
*Emphasize process skills (problem solving, critical & creative thinking, etc).(1,3,5,7,10)
*Emphasize the relevance of science and technology in daily life.(8,11)
*Need knowledge of key concepts and principles.(1,2,8,11)
*Emphasize careers in science and technology.(8,11)
*Emphasize writing as a communication tool.(2,11)
*Dynamic nature of science. (2,11)
*Evolution.(1,2)
*History of science.(2,10)

APPROACH

*Promote scientific literacy.(1,5,8,10,11)
*Science should be hands-on learning.(3,8)
*Need more instructional time for science.(3,5,7,8,11)
*Use interdisciplinary approach to science.(1,2,5,8)
*Encourage minority students in MSE.(2,6)
*Need better evaluation methods.(2,3,8,11)
*Integrate teaching of science, math & technology.(1,2)
*All teachers need science background.(2,3,8)
*Quality of teaching needs improvement.(1,3,8,11)
*Inquiry based-start with question, not an answer.(1,11)
*Need great access to classroom lab facilities.(7,9)

DIFFERENCES

CONTENT CONSIDERATIONS

*Scale and proportion of universe.(8)
*Cause and effect relationships.(2)
*Patterns of change.(1)
*Decrease amount of content covered.(1)
*Understand applications of technology & responsibility for decisions related to it.(11)
*Appreciation for uses, benefits & limitations of science in society.(8)
*In K-6 focus on natural phenomena & problems in child's environment. In 7-8 teach biological, chemical & physical aspects of human beings.(8)
*Organize around real life issues & personal & community decision making.(8)
*Understand application of technology.(11)
*Benefits as well as limitations of science in advancing human progress.(11)
*Values in science and technology.(2)
*Scientists beliefs and assumptions about natural world.(9)
*Identify & solve real problems.(9)
*Nature of scientific process.(10)
*Include "non-science-specific notions" such as ethical judgment, probablistic reasoning and risk assessment.(5)

APPROACH

*Lengthen school year.(3)
*Differentiate for ability levels.(8)
*Science taught as a liberal art.(2)
*Make science accessible to disabled.(2)
*Develop incentives for elementary teachers to take more science courses.(3)
*Use homework & other time extenders.(3)
*Set school priorities and give parents choices among them.(3)
*Science classes should interact with community.(8)
*Teachers should be required to have computer skills.(8)
*Math, science & technology-not just for pre-professional students.(8)
*Continuous curricular review & updating.(8)
*Organize around major themes (e.g. models change, etc) (1)
*More preservice training in science.(7)
*Preservice teachers need courses in history, philosophy, & applications of science.(7)
*New approaches to preservice & inservice training.(5)
*More effective use of educational research.(5)
*Promote technological literacy.(5)

REFERENCES

(1) American Association for the Advancement of Science (1989). Science for All Americans. (AAAS Publication 89-01S). Washington, DC: Author.

(2) American Association for the Advancement of Science (1990). The Liberal Art of Science. (AAAS Publication 90-13S). Washington, DC: Author.

(3) Bennett, W.J. (1986). First Lessons: A Report on Elementary Education in America. Washington, DC: U.S. Government Printing Office.

(4) Carnegie Form on Education and the Economy, Task Force on Teaching as a Profession (1986). A Nation Prepared: Teachers for the 21st Century. NY: Author.

(5) Exxon Education Foundation (1984). Science Education in the United States: Essential Steps for Achieving Fundamental Improvement. NY: Author.

(6) Hilton, T.L., Hsia, J., Solorzano, D.G., & Benton, N.L. (1989). Persistence in Science of High-Ability Minority Students. Princeton, NJ: Educational Testing Service.

(7) Mullis, I.V.S. & Jenkins, L.B. (1988). The Science Report Card, Elements of Risk and Discovery. Princeton, NJ: Educational Testing Service.

(8) The National Science Board Commission on Precollege Education in Mathematics, Science, and Technology (1983). Educating Americans for the 21st Century Washington, DC: National Science Foundation.

(9) National Assessment of Educational Progress (1988). Science Learning Matters. Princeton, NJ: Educational Testing Service.

(10 National Assessment of Educational Progress (1989). Science Objectives. 1990 Assessment. Princeton, NJ: Educational Testing Service.

(11) Texas Education Agency (1987). Science Framework, Kindergarten-Grade 12. Austin, Texas.